Spallation Neutron Source

High QA Machine Protection System SRD

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A U.S. Department of Energy Multilaboratory Project

SPALLATION NEUTRON SOURCE

Argonne National Laboratory • Brookhaven National Laboratory • Thomas Jefferson National Accelerator Facility • Lawrence Berkeley National Laboratory • Los Alamos National Laboratory • Oak Ridge National Laboratory

SNS

SPALLATION NEUTRON SOURCE
SYSTEMS REQUIREMENTS DOCUMENT
FOR High QA Machine Protection System

Revised September 2001

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Preface

There are several systems, such as the mercury target and beam dumps, that require a highly reliable, configuration controlled, machine protection system which implies redundancy and strict configuration controls. The MPS Fast Protect Systems do not have redundancy and cannot meet some configuration control standards, specifically when software masks and software trip points are implemented. The actions appropriate to the quality level of the High QA Machine Protection System (HQA-MPS) will follow the guidelines dictated in the SNS QA plan document (SNS 102040000QA0001R02).

The HQA-MPS integrates with the systems listed in Table A. The person potentially identified at this time is the contact person between the HQA system and the subsystem. The signal condition is performed in the system indicated.

System	Signal	Contact Person	Signal conditioned by:
HARPS	Comparator level on selected wire sets	Tom Shea	Diagnostics
Integrated Beam Current Monitors	Comparator on integrated charge	Tom Shea	Diagnostics
Differential Beam Current Monitors	Trip level on differential charge	Tom Shea	Diagnostics
Beam Loss Monitors	Trip level on total loss	Tom Shea	Diagnostics
Magnet Current Sensors	Window comparator on magnet currents	Controls / SNS PS Group	Controls (Hardware and PLC signal conditioning)
Accelerator Physics	Physics model set points	John Galambos	NA
Target Controls	Contacts indicating sum of control points	Ron Battle	Target Controls
Dump Controls	Sum of Thermocouple trip point comparators. Analog signals processed in EPICS	John Smith	Commercial thermocouple conditioner module
PPS Inputs	Dry contacts	Paul Wright	MPS PLC
65 kV Power Supply status	Low when power supply off	Martin Stockley	MPS PLC
RFQ Power supply status	Low when power supply off	Martin Stockly	MPS PLC
PPS Outputs	Open contacts in fail state	Paul Wright	PPS

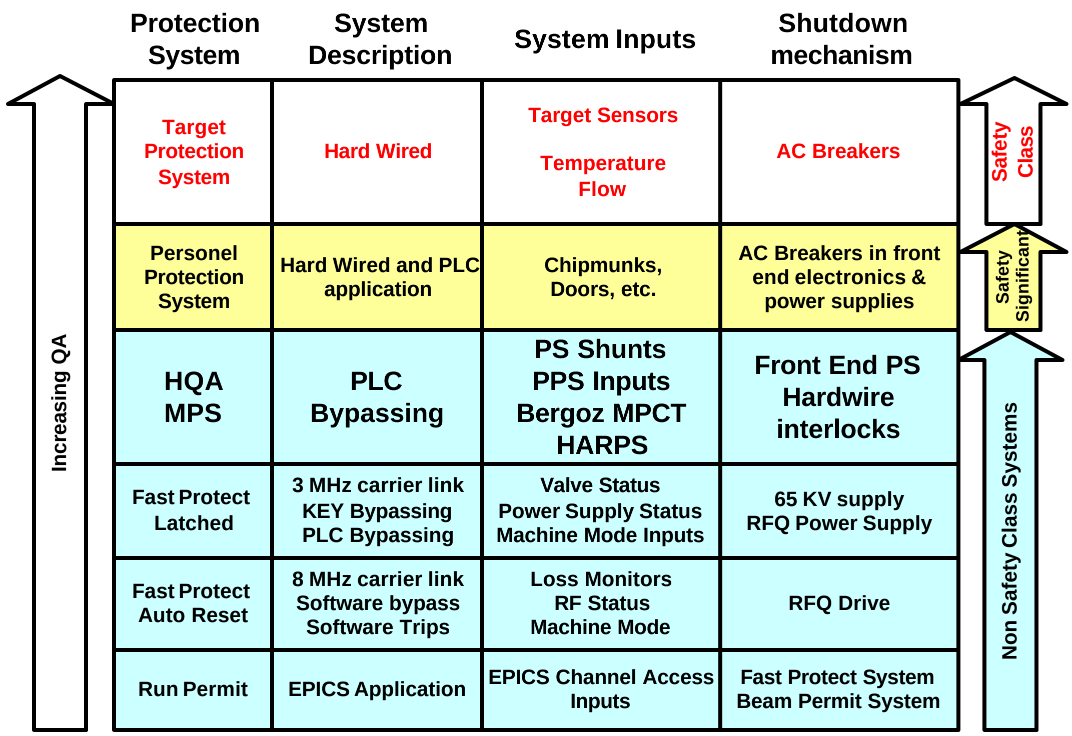

Figure 1. Machine Protection Hierarchy

Introduction

The Machine Protection System consists of four subsystems, Run Permit, Fast Protect Auto Reset, Fast Protect Latched, and a Hard Wired System. The Machine Protection System (MPS) does not protect personnel and is not a safety class or safety significant system. There are several system that have a high cost involved in the event of damage due to beam conditions, both in terms of replacement cost and machine downtime. The mercury target and beam dumps fall into this category. Due to the consequences of potential damage or machine downtime, a separate MPS system, the High QA Machine Protection System is required. The HQA-MPS system, needs to be highly reliable, fail-safe and under configuration control. Although there are no requirements for redundancy within each of the MPS subsystems, redundancy is explicit in most cases from the perspective of "Defense in Depth".

The HQA-MPS system must shut down the beam within two beam pulses of detecting a fault. Some inputs to the HQA system may redundant. The magnet current monitoring sensors are chosen to ensure beam optics changes are not made which could create a detrimental beam size or steer the beam off the mercury target. The shutdown requirements for the target station shown below come from SNS 106000000-IC0004-R01, SNS ICD Target Systems and Ring Systems. EPICS will provide time stamps of fault conditions.

The Fast Protect Auto Reset shuts down the FPS carrier signal upon detecting an input in a failed state. Detection of loss of the carrier results in beam cutoff in less than 20 usec. If the fault condition goes away, the output will be reset on the next Cycle Start Event. Typical inputs are Beam Loss Monitors and RF Faults.

The Fast Protect Latched system shuts down the FPL carrier signal upon detecting an input in a failed state. Detection of loss of the carrier results in beam cutoff in less than 20 usec. The fault condition must be cleared and the MPS trip cleared before beam is permitted. Typical inputs are from Power Supplies, Vacuum systems, etc.

The Run Permit System is a software application providing a first line of defense. The RPS verifies beam power according to the machine mode, sets up the machine running sequence-scheduling user defined beam profiles at the desired rates and verifies the configuration of the MPS hardware.

	Normal condition	**Off-normal**	**Duration of fault**	**Protected / Monitored by**
Target cross section width Height	404 mm 104 mm			
Beam spot width height	200 mm 70 mm			HARP / PS Monitors
Beam power within nominal beam spot	> 90 %	> 50% power outside spot	<= 2 pulses	HARP /Beam current monitor PS Monitors
Time-average beam current density over spot	<= 0.143 A/m^2 (2 MW)			Current monitor HARP
Peak time-average beam current density	0.25 A/m^2	<= 0.28 A/m^2	10 seconds	Current monitor HARP
Peak single pulse density	<= 2.6 x 10^{16} protons/m^2	<= 3.20 x 10^{16} protons/m^2	<= 2 pulses	HARP Beam Current Monitor
Tolerance on beam centroid horizontal vertical	± 2 mm ± 2 mm			HARP BPM Corrector I monitor
Unscheduled beam-off > 5 seconds > 5 minutes	<= 50 per day <= 10 per day			EPICS

Table 1. 2-MW Beam interface requirements with the target shroud face

The beam dumps have different requirements than the target. The linac dump and extraction dump are passively cooled and are rated at 7.5 kW. The injection dump is water-cooled and is rated at 200 kW. The beam parameters at the three dumps are listed in SNS document number 106000000-IC0004-R01, SNS ICD Target Systems and Ring

Systems. The beam characteristics on the windows are also monitored, and can be the limiting factor for a beam permit signal. Due to beam scattering from the window, the limiting power density is at the window, not at the dump. The spreadsheet in appendix A shows that the current comparator windows can be set from +20% to –50% and still meet the current density requirement on the linac dump. Limits for beam allowed on the dumps will first be set by calculation and later (possibly) iterated based upon empirical results with beam.

The requirements for beam parameters on the 4 windows are TBD. Calculations are in progress to define the acceptable beam intensity on each of the windows.

Inputs to the HQA system

The HQA-MPS system provides an additional layer of defense for the target and dump systems. The systems interfacing to the HQA-MPS will be designed for high availability and fail-safe outputs. Inputs to the HQA protect system come from power supplies, target and dump protection systems, the Personnel Protection System, a key bank selection chassis, harps, beam loss monitors (BLM) and beam current monitors (BCM). The outputs of the HQA PLC system control the ON status of at least two power supplies in the ion source, and determine which power monitor circuit output is used as an input to the fast systems.

Outputs from the HQA system include two sets of contacts to the 65 kV power supply and two set to the RFQ Power supply. The MPS monitors the shutdown status of the two power supplies and will open a contact to the PPS if the supplies did not shut down as requested.

Magnet Current Inputs

The quadrupole current monitoring devices with window comparators are used to ensure the beam is defocused on the dumps, target, and windows. The trip set points are determined by the nominal beam size on the target or dump (window) by the Accelerator Physics Group. The trip limits are defined so the beam size is large enough to not exceed the maximum allowable current density (table 1) and so the fraction of beam outside the allowable area is less than the fractional loss due to scattering from the window.

Dipole monitors have two sets of trip points, nominal bending angle and no bend. The nominal bending angle trip settings for commissioning are set for +/- 5% of the nominal current for a 1 GeV beam. The no bend trip point is set at 1% of the nominal 1GeV setting. This limits losses and will not allow beam if a dipole is inadvertently turned on.

Corrector dipoles may be monitored using a window comparator circuit if required. The need to do so will be determined on a case-by-case basis and implemented where necessary. The EPICS Control system and the Alarm handler also monitor the corrector dipoles in the RTBT after the HARPS.

1. Absolute accuracy, repeatability and setability values of the trip currents.

Current Sensor Accuracy 0.1%

Current Sensor Read back Voltage, 4 to 20 ma. or 0 – 10V.

ADC Resolution 12 bits (11 bits + sign)
Trip Point Accuracy 0.1% (Actually ADC resolution)
Trip point read back resolution, IEEE floating point number.
Current sensor status bit

2. Location of current sensors and electronics

The shunts and electronics should be considered QA2 level protection devices. As such, they should be located in a configuration-controlled cabinet under lock and key. The current sensors should not be located in the power supply, but in series with the magnet.

3. Choice of technology

The sensor should be fail-safe. If the sensor and / or electronics lose power (or regulation) the digital output should indicate a fault. Control Net is a deterministic network for communication with remote devices. The input modules are set to scan at deterministic rates, and communication errors result if the rates cannot be met.

4. Method of implementation –

- PLC Control –
  - Analog Inputs: Shunt Currents
    - Scan Time
    - Conversion Time
    - Step response
  - Digital Inputs: 24v DC status of current transducer
    - Relay contacts or 24 VDC from Machine Mode
  - PLC Inputs: Remote FLEX IO block status
    - Control Net communication status
  - Outputs:
    - 65 kV Power supply contacts, NC, open in a fault condition
    - RFQ Power supply contacts, NC, open in a fault condition
    - 1 binary output per dump for FPS
  - PLC Internal states
    - LDMP_enable, LDMP_disable,
    - IDMP_enable, IDMP_disable,
    - RING_enable, RING_disable,
    - EDMP_enable, EDMP_disable,
    - TGT_enable, TGT_disable

Power supply	1 GeV (1)	Max	Max	Sensor	HI (2)	LO (3)	(4)
	Current	Current	Volts	Max	Trip	Trip	Dump
LDMP_PS:QH1	238	300	20	300	±5%		LDMP
LDMP_PS:QV2	238	300	20	300	±5%		LDMP
LDMP_PS:QH3_4	277	300	20	300	±5%		LDMP
LDMP_PS:QV5_6	198	300	20	300	±5%		LDMP
HEBT_PS:DH11	616	700	40	1000		6.16	LDMP
HEBT_PS:DH11	616	700	40	1000	±5%		I,R,E,T
HEBT_PS:DH12_thr_18	616	700	40	1000	±5%		I,R,E,T

IDMP_PS:QV1	665	750	35	1000	±5%		I,R,E,T
Ring_PS:InjKH13A Ring_PS:InjKH13B Ring_PS:InjKV13A Ring_PS:InjKV13B Ring_PS:InjKH9A Ring_PS:InjKH9B Ring_PS:InjKV9A Ring_PS:InjKV9B	Status only						I,R,E,T
RTBT_PS:ExSptm	2088	2500	60	3000		20.8	RING
RTBT_PS:ExSptm	2088	2500	60	3000	±5%		E,T
RTBT_PS:DH13	1465	2000	50	3000		14.6	EDMP
EDMP:PS:QH1	724	800	75	1000	±5%		EDMP
EDMP:PS:QV2	724	800	75	1000	±5%		EDMP
RTBT_PS:DH13	1465	2000	50	3000	±5%		TGT
RTBT_PS:QH26	849	1250	75	3000	±5%		TGT
RTBT_PS:QV27	849	1250	75	3000	±5%		TGT
RTBT_PS:QH28	849	1250	75	3000	±5%		TGT
RTBT_PS:QV29	849	1250	75	3000	±5%		TGT
RTBT_PS:QH30	849	1250	75	3000	±5%		TGT
RTBT_PS:QH31	849	1250	75	3000	±5%		TGT
RTBT_PS:DCH26	0	±120	±35	300	±5%		TGT
RTBT_PS:DCV26	0	±120	±35	300	±5%		TGT
RTBT_PS:DCH28	0	±120	±35	300	±5%		TGT
RTBT_PS:DCV28	0	±120	±35	300	±5%		TGT
RTBT_PS:DCH30	0	±120	±35	300	±5%		TGT
RTBT_PS:DCV30	0	±120	±35	300	±5%		TGT

Table 2. Some example magnet current inputs, default trip points.
(1) Nominal current setting indicates preliminary estimates of magnet currents. Actual settings will be determined during commissioning on a case by case basis.
(2), (3) Actual settings will be determined during commissioning.
(4) I,R,E,T – Injection dump, RING, extraction dump, or target

Control Net
Producer – consumer model
Scheduled updates (Deterministic)

Dump – Target Protection System Inputs

The linac dump and extraction dump are passive dumps and thus have no cooling systems. The only inputs from these dumps are the outputs from thermocouple comparators.

The injection dump is an actively cooled dump capable of dissipating 200 kW of beam power. The dump protection system combines interlocks from water flow, temperature, and pump status inputs and provides a redundant set of contacts to the HQA system. The injection dump is required for any beam into the injection dump, ring, extraction dump, and target.

The mercury target is capable of handling 2 MW of beam power. The target protection system combines mercury temperature and flow interlocks and provides redundant contacts to the HQA system. The beam parameters and requirements on target are described in the SNS 106000000-IC0004-R01 document. The target can take a maximum of 2 off NORMAL pulses in a row running at 60 Hz. The design criteria document for the target is described in SNS 106080000-DC0001.

Beam Diagnostics Inputs

There are two types of HARPS that will be deployed, a target harp installed in the proton beam window box, and retractable sets in each of the dump / target beamlines. The target harp is replaced with the PBW as infrequently at once per year. When this assembly is first installed, it is used to qualify the upstream HARP sets. These redundant, retractable harps will be installed 180 degrees upstream of the target harp and measure the beam current density at that point. If the target harp fails, its input to HQMPS is masked and the upstream retractable harps are inserted and used instead. The HARP electronics must be capable of supplying the MPS system with GO / NOGO signals on a pulse-by-pulse basis. The purpose of the HARP is to verify that the beam intensity on the window and dump remains below the specifications and the beam position on the window and dump remains within specifications. The signals from the harps must be combined to a GO, NOGO latched signal to the HQA-MPS. 24v DC signals will go to the HQA-MPS and TTL level signals driving optocouplers will go to the latched FPS system.

There are at least two possible problems with long-term use of HARPS as a pulse-to-pulse qualifying device. The secondary emission coefficient is reduced with increasing doses of radiation and the wire degrades, eventually leading to breakage.. A pulse stealing technique will be used to monitor the long-term health of the wires in the RTBT. By selecting a minipulse at varying times during the injection process, the mini pulse can be raster scanned across the HARP. By monitoring the peak amplitudes of the minipulse, the degradation due to changes in the secondary emission coefficients can be monitored and used to correct the measurements. The integrated current, integrated current density, and integrated beam losses are logged through the EPICS control system.

There are at least two integrating current monitors installed, one at the end of the linac and one in the injection dump line. Beam loss monitors detect if the core of the transformer is getting hit with beam or spray protect both current monitors. These monitors are used to monitor the average beam current and are used to shut off the beam if the beam power is greater than the input limit. Beam Current Monitors may also be used in a Beam Accounting System.

Personnel Protection System

The inputs from the Personnel Protection System (PPS) are the status of the beam permit inputs for the different areas. The PPS gives a closed contact to indicate a beam area is ready to accept beam or is in Beam Permit Mode. There are five inputs: linac, HEBT, ring, RTBT, and target. Beam is not permitted unless the area(s) are in beam permit.

Control Room Inputs

There will be two key switches in the control room to select the beam dump, maximum beam power, and maximum pulse length. The following figure shows the key positions. The beam power indication is the maximum power permitted. Software can always request lower power limits. The maximum pulse duration will limit the pulse rate to suitable rates depending on the dump. Table 3 shows rep rate limits for different pulse lengths. Pulse lengths are integrated beam on times during a macro pulse.

Width	Max Rep Rate @ 1 GeV, 38.2ma		
(usec)	7500	2.00E+05	2.00E+06
10	19.63	60.00	60.00
50	3.93	60.00	60.00
100	1.96	52.36	60.00
680	0.29	7.70	60.00

Table 3. Maximum rep rate for unchopped beam of various pulse widths

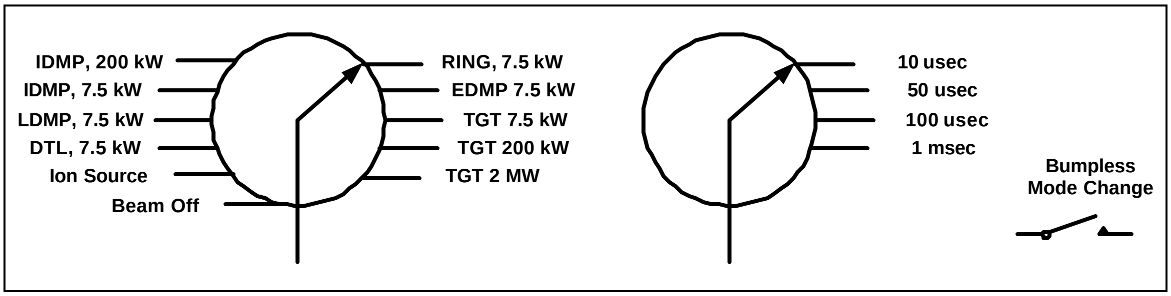

Figure 2. Key switches for beam dump / power selection and maximum Pulse Width selection.

Software inputs

An EPICS application will be allowed to change the machine power or pulse width limits to a lower value. This can be done for wire scans or emittance measurements. Hardware limits the upper range of beam power or pulse width to that selected by the key bank.

The Timing system provides a "Time Line Monitor" to record the time stamps when events occurred and the data on the RTDL link. One of the functions of the Run Permit System is to use this Time Line Monitor to verify the programming sequence of the machine, and to shut off beam if discrepancies are found. This is one level of protection in the defense in depth strategy.

Quality Assurance Requirements

All activities associated with the HQA-MPS system will be conducted in accordance with the SNS Quality Assurance Plan (SNS-QA-PO1). The appropriate grade is QA2 for this system. Complete system testing is required at least once per year. Equipment is to be maintained in locked enclosures with electronic logbooks serving as a documentation media. PLC software changes made in the logic require system verification after completion and a new version number. Software changes to constants (i.e. a trip level) require verification for that device and a logbook entry.

System Architecture

The hardware architecture of the HQA-MPS uses an Allen Bradley PLC and control net to communicate to the remote FLEX IO hardware. Appendix B lists the technical specifications for ControlNet. The HQA system will use the FLEX IO 1794 Series of ADC's. The IE8 module has 8 single ended inputs, user selectable voltage or current input levels, and converts 8 channels in 256 µsec. Although the step response (0 to 63% is slow, 9.4 msec, the windows will be set to around 5% of the setting. Tests indicate a worst-case response from a fault input to an open contact output of around 12-msec. for two remote nodes with 24 AI on one node, 16 AI on the second and 8 BO on the PLC. The scan rates were set for 4 msec. This should represent the worst case for the fully loaded system so we expect to latch a fault in less than 16 msec. The total logic involved in the test is approximately 25% of that required for a full system. The Logic scan time was ~500 µsec.

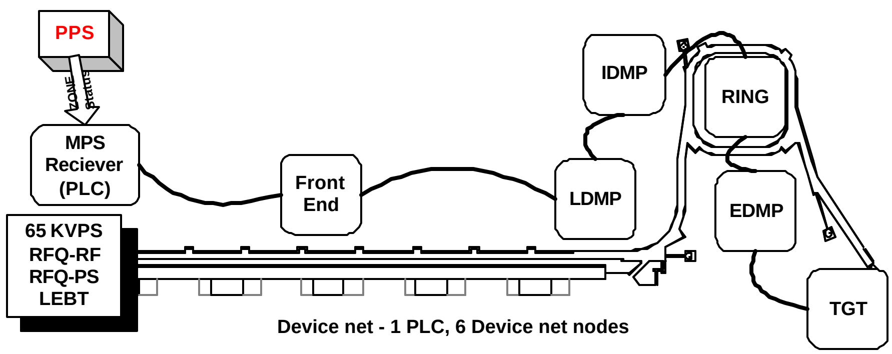

Figure 3. System layout of the HQA-MPS.

PLC Logic Description

Beam OFF

The contacts for the 65 kV PS and the RFQ PS stay open.

Ion Source, D-Plate

The 65 kV PS contacts are closed, allowing the power supply to be turned on. The PPS locks out the 65 kV supply or the plasma RF supply so both are not enabled at the same time. The second critical device, the RFQ power supply is locked out by the PPS.

LDMP, IDMP, RING, EDMP, TGT

The matrix defined in Table 4 shows the logic states for some of the possible external inputs that may be required for beam to be permitted. When beam is permitted the contacts for the 65 kV supply and the RFQ power supply are closed. For each dump indicated, the associated communications and FLEX IO module status are required to be satisfied. There are three types of inputs, binary, window comparators, and high trip levels. The binary inputs are satisfied if the input = 24V or a set of contacts are closed, not satisfied otherwise. The window comparators have a high trip and low trip level. The input is satisfied if it is above the low trip point and below the high trip point. The

High trip inputs are satisfied if the input is below the high trip level. Some analog inputs have an unsatisfied condition in one beam mode and a satisfied condition in other modes.

Input	Input type	LDMP	IDMP	RING	EDMP	TGT
PPS_LINAC	Binary	Y	Y	Y	Y	Y
LDMP_PS:QH1	Window	Y	-	-	-	-
LDMP_PS:QV2	Window	Y	-	-	-	-
LDMP_PS:QH3_4	Window	Y	-	-	-	-
LDMP_PS:QV5_6	Window	Y	-	-	-	-
HEBT_PS:DH11:LOW	High_Trip	Y	N	N	N	N
PPS_HEBT	Binary	Y	Y	Y	Y	Y
PPS_RING	Binary	Y	Y	Y	Y	Y
LDMP_Diagnostics	Binary	Y	-	-	-	-
HEBT_PS:DH11:HIGH	Window	N	Y	Y	Y	Y
HEBT_PS:DH12_thr_18	Window	-	Y	Y	Y	Y
IDMP_PS:QV1	Window	-	Y	Y	Y	Y
Inj Kickers	Binary	-	Y	Y	Y	Y
IDMP_Diagnostics	Binary	-	Y	Y	Y	Y
PPS_RTBT	Binary	-	-	Y	Y	Y
PPS_TGT	Binary	-	-	-	Y	Y
RTBT_PS:E-Sptm:LO	High_Trip	-	-	Y	N	N
RTBT_PS:E-Sptm:HI	Window	-	-	N	Y	Y
RTBT_PS:DH13:LO	High_Trip	-	-	-	Y	N
EDMP:PS:QH1	Window	-	-	-	Y	-
EDMP:PS:QV2	Window	-	-	-	Y	-
EDMP_Diagnostics	Binary	-	-	-	Y	-
RTBT_PS:DH13:HI	Window	-	-	-	N	Y
RTBT_PS:QH26	Window	-	-	-	-	Y
RTBT_PS:QV27	Window	-	-	-	-	Y
RTBT_PS:QH28	Window	-	-	-	-	Y
RTBT_PS:QV29	Window	-	-	-	-	Y
RTBT_PS:QH30	Window	-	-	-	-	Y
RTBT_PS:QH31	Window	-	-	-	-	Y
RTBT_PS:DCH26	Window	-	-	-	-	Y
RTBT_PS:DCV26	Window	-	-	-	-	Y
RTBT_PS:DCH28	Window	-	-	-	-	Y
RTBT_PS:DCV28	Window	-	-	-	-	Y
RTBT_PS:DCH30	Window	-	-	-	-	Y
RTBT_PS:DCV30	Window	-	-	-	-	Y
TGT_Diagnostics	Binary	-	-	-	-	Y

Table 4. HQA-MPS logic matrix, Y – Input satisfied, N – Input not satisfied, '-' don't care.

Appendix A

Effects of quad setting on current density at the linac dump and linac dump Window. (E-mail Deepak Raparia 7-17-01)

Current Density at Linac dump				
	Nominal			5e-3 limit A/m^2
Quad #	Gradient	Quad setting	Transmission from window to dump	Max Current Density A/m^2
	T/m		out/in	
Quad 12	2.61431		5547/5610	9.93E-04
		5% up	5547/5610	9.67E-04
		5% down	5547/5610	9.34E-04
		10% up	5549/5610	9.72E-04
		10% down	5546/5610	9.02E-04
Quad 13/11	1.93365	5% up	5590/5610	9.67E-04
		5% down	5547/5610	9.54E-04
		10% up	5546/5610	9.76E-04
		10%down	5547/5610	9.37E-04
Quad 14/15	3.03287	10% up	5546/5610	8.96E-04
		10% down	5547/5610	9.36E-04
		20%up	5546/5610	8.17E-04
		20% down	5548/5610	9.93E-04
Quad 16/17	3.10172	20% up	5545/5610	8.29E-04
		50% up	5541/5610	6.54E-04
		50% down	5549/5610	1.33E-04
			Current density at window	
Normal			5610/5610	8.40E-02
Quad 16/17	3.10172	10% up	5610/5610	1.06E-01
		10% down	5610/5610	6.01E-02
Quad 14/15	3.03287	10% up	5610/5610	7.18E-02
		10% down	5610/5610	9.58E-02
		20% up	5610/5610	5.97E-02
		20% down	5610/5610	9.14E-02
quad 12	2.61431	20% up	5610/5610	1.40E-01
		20% down	5610/5610	3.77E-02
Ququd 13/11	1.93265	20% up	5610/5610	7.26E-02
		20% down	5610/5610	7.40E-02

Note: The SNS Accelerator Physics Group continues their efforts to determine exactly which elements (individually and collectively) should be required as inputs to the MPS systems.

Appendix B

ControlNet Technical Specifications

Type of Bus
- Control
- I/O data, Programming data on same wire

Bus Topologies
- Linear Trunk
- Tree
- Star
- Mix of any of above

Bus Speed
- 5.0 megabit/sec (maximum)

Length, single segment
- 1,000 m (coax) @ 5 Mb/s
- 1,000 m with two nodes
- 250 m with 48 nodes
- 3,000 m (fiber) @ 5 Mb/s

Number of Repeaters
- 5 (maximum) in series
- 6 segments (5 repeaters) in series
- 48 segments in parallel

Maximum Length with Repeaters
- 5,000 m (coax) @ 5 Mb/s
- 30+ km (fiber)

Types of Repeaters
- high voltage ac & dc
- low voltage dc

Device Power
- Devices powered externally

Connectors (Standard Coax BNC)
- barrel (plug-to-plug)
- bullet (jack-to-jack)
- extender (plug-to-jack)
- isolated bulkhead (jack-to-jack)
- right angle (plug-to-jack)

Communication Model
- Producer/Consumer

Number of Nodes
- 99 Maximum Addressable Nodes
- 48 taps (nodes) without a repeater

Size of Data Packet
- Variable, 0-510 bytes

Number of I/O Data Points

- No limit

Network Update Time (Scan Time)
- 2-100 msec (user selectable)

Communication Modes (Bus-Addressing)
- Master/Slave
- Mulit-Master
- Peer-to-Peer

I/O Data Triggers
- Polling
- Cyclic
- Change-of-State

Cyclic Redundancy Check
- Modified CCITT using 16-bit, polynomial

Application Layer
- Object-Oriented: Class/Instance/Attribute
- Device Object Model using Device Profiles

Physical Media
- coax - R6/U
- fiber

Network and System Features
- Remove/Insert Devices Under Power
- Deterministic, Repeatable
- Intrinsic Safety Option
- Duplicate Node ID Detection
- Message Fragmentation (block transfers)